Specification of PEEM3 microscope design

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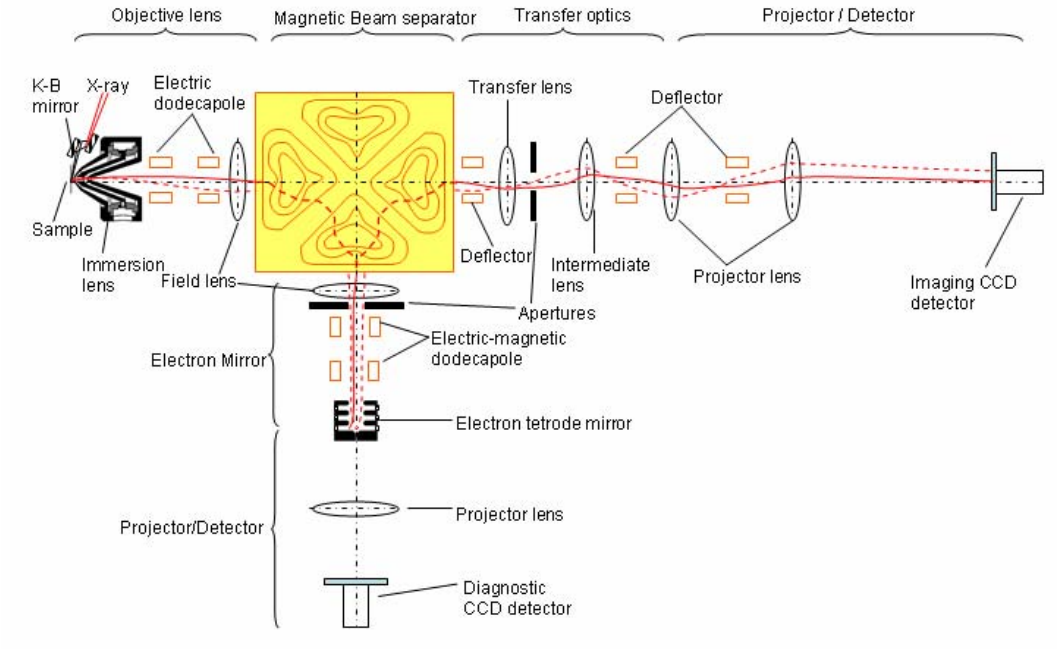
PEEM3 is a large project. The whole project includes the construction of a new state-of-art EPU beam-line and an aberration-corrected photoemission electron microscope capable of 5nm resolution. This note gives the technical specification of PEEM3 microscope lens, mirror, stigmator/deflector aperture and layout, which is used as a guide of mechanical engineer design. The physics design of PEEM3 is in another note.

1. PEEM3 system

PEEM3 microscope is the third generation photoemission electron microscope at the Advanced Light Source. PEEM3 microscope consists of objective lens, electric-magnetic dodecapole, magnetic beam separator, electron mirror, transfer and projector lens. Fig.1 shows the schematic overview of PEEM3. An elliptically polarized undulator (EPU) at the straight sector 11 of the ALS will be used to produced in-plan linear, perpendicular linear, left and right handed circularly polarized radiation with continuous change of ellipticity. A variable line space (VLS) plane grating monochromator beamline will provide soft x-ray in the spectral range from 100eV to 1500eV. Variable beam sizes on sample from 3micron to 50 micron are carried out by a pair of bendable K-B mirror. Additionally, a UV-lamps and a laser system will be mounted to the sample chamber. The critical components of PEEM3 are the electron mirror aberration corrector and aberration-free magnetic beam separator.



Concept of a X-ray photoemission electron microscope using electron mirror corrector at the ALS

Fig.1 Schematic layout of a X-ray photoemission electron microscope using electron mirror corrector at the ALS

2. PEEM3 front end

PEEM3 front end is from sample to the entrance plan of separator. It consists of 1) one objective lens system, 2) two new designed field lens. 3) two electrostatic dodecapole . Fig.2 gives the layout. O is objective lens, which is a pure electrostatic four electrode lens which the sample is part of the lens and is modified from PEEM2 to have smaller aberrations. D1, D2 are electrostatic dodecapole. They can work as double-deflection element to align the electron angle and position separately, or work as stigmator. F1 is first field lens. The design gap between sample and first electrode of objective is 2mm. But this distance should be adjustable depending on sample situation. The outer surface of last electrode of field lens is 178.18mm away from the inner surface of sample. The entrance plan of separator is 184.18mm away from the sample. The position of D1 and D2 depends on the available space between the two lens and should be separated in a reasonable distance.

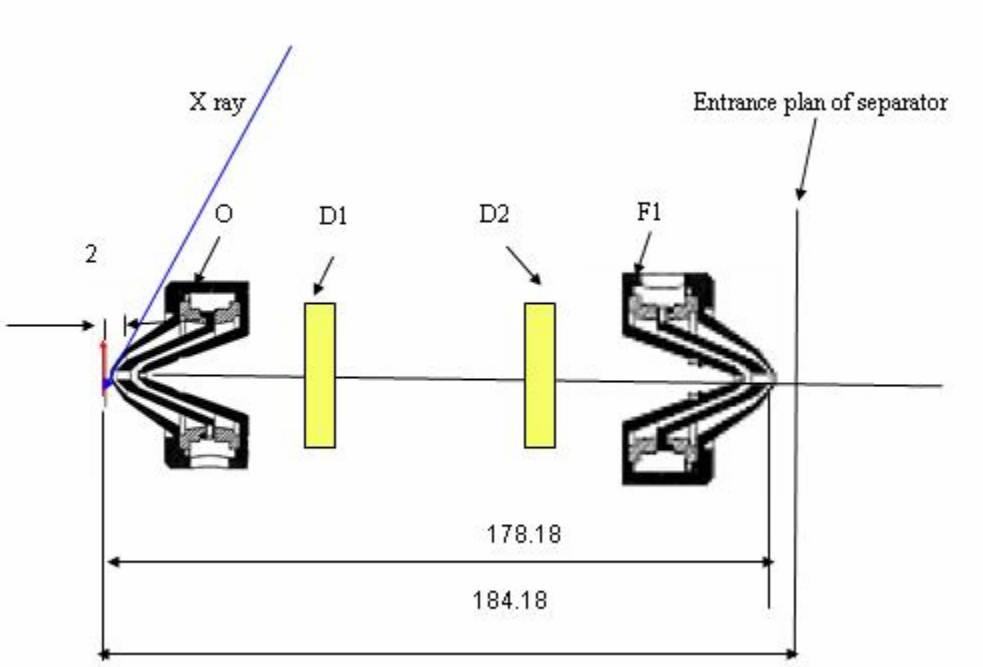


Fig.2 Front end column layout

1) objective lens

The detail dimension of the objective lens is shown in fig.3 and the coordinate is given in the following table..

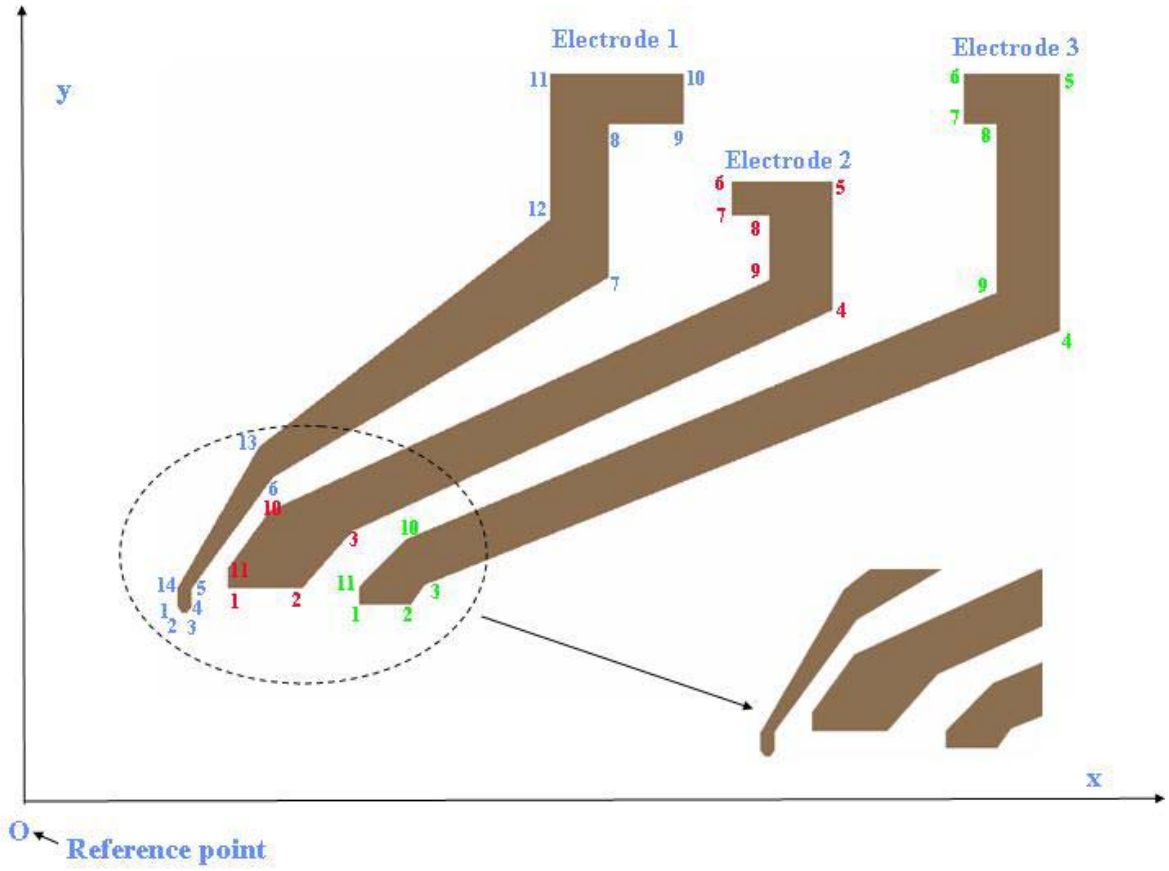


Fig.3 Convention of objective lens coordinates. The number in the figure is the order of the coordinate. Different color of the number corresponds to name different electrodes. O is the reference point.

The coordinates of different electrodes for objective are as following:

	order	X(mm)	Y(mm)
Electrode1	1	5.5	0.85
	2	5.75	0.5
	3	6.05	0.5
	4	6.3	0.85
	5	6.3	1.95
	6	11.2	8.65
	7	31.5	20.75
	8	31.5	30
	9	36	30
	10	36	32.95
	11	28	32.95
	12	28	24.15
	13	10.45	10.45
	14	5.5	1.9
Electrode 2	1	8.55	2
	2	13	2
	3	16	5.4
	4	45	18.75
	5	45	26.45
	6	39	26.45
	7	39	24.5
	8	41.25	24.5
	9	41.25	20.5
	10	11.05	6.55
	11	8.55	3.1
Electrode 3	1	16.5	1
	2	19.55	1
	3	20.35	2.15
	4	58.75	17.5
	5	58.75	32.95
	6	53	32.95
	7	53	30
	8	55	30
	9	55	19.75
	10	19.3	4.85
	11	16.5	2

2) Field Lens F1
Fig.4 gives the dimension and the coordinate convention of field lens.

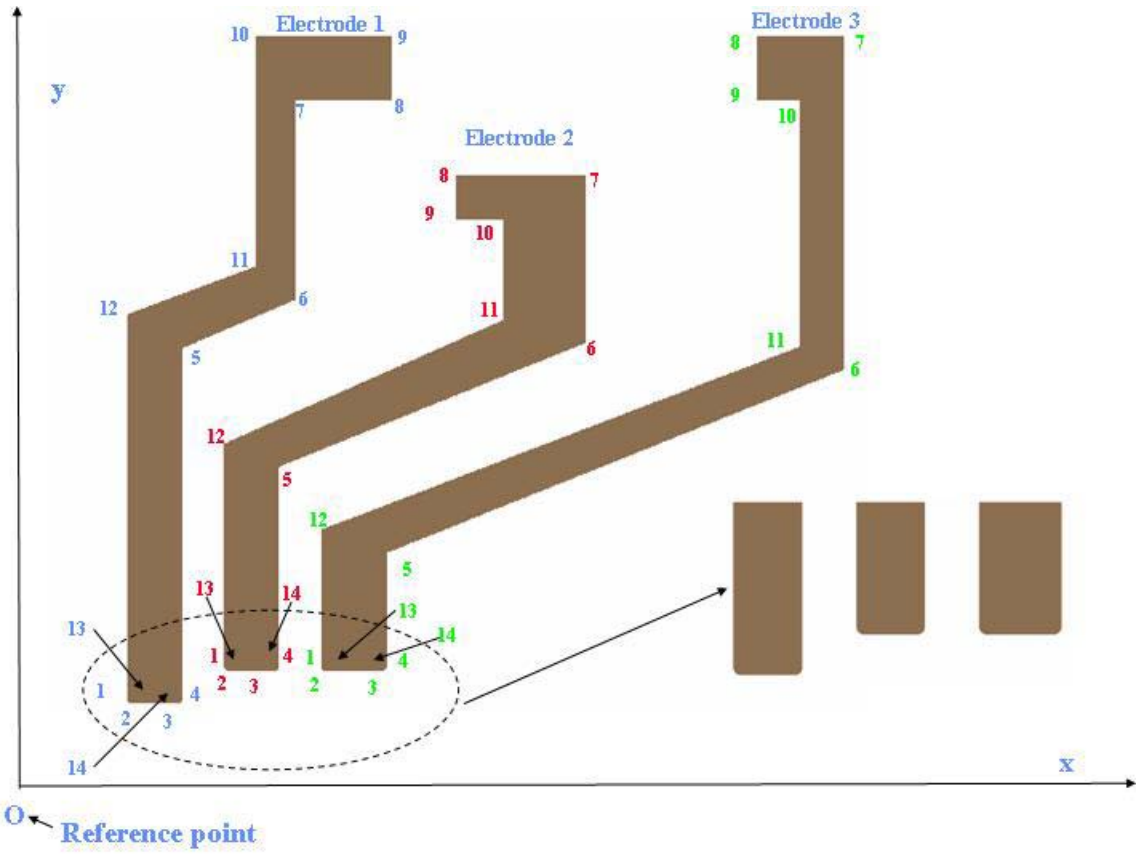


Fig.4 Convention of field lens coordinates. The number in the figure is the order of the coordinate. Different color of the number corresponds to name different electrodes. O is the reference point.

The coordinates of different electrodes for filed lens are as following:

	Order	x(mm)	y(mm)	Radius (mm)
Electrode 1	1	23.75	2.25	
	2	24	2	
	3	26	2	
	4	26.25	2.25	
	5	26.25	18.5	
	6	31.5	20.75	
	7	31.5	30	
	8	36	30	
	9	36	32.95	
	10	29.75	32.95	
	11	29.75	22.25	
	12	23.75	20	
	13	24	2.25	0.25
	14	26	2.25	0.25
Electrode 2	1	28.25	3.75	
	2	28.5	3.5	
	3	30.5	3.5	
	4	30.75	3.75	
	5	30.75	13	
	6	45	18.75	
	7	45	26.45	
	8	39	26.45	
	9	39	24.5	
	10	41.25	24.5	
	11	41.25	19.75	
	12	28.25	14	
	13	28.5	3.75	0.25
	14	30.5	3.75	0.25
Electrode 3	1	32.75	3.75	
	2	33	3.5	
	3	35.5	3.5	
	4	35.75	3.75	
	5	35.75	9	
	6	57	17.5	
	7	57	32.95	
	8	53	32.95	
	9	53	30	
	10	55	30	
	11	55	18.5	
	12	32.75	10	
	13	33	3.75	0.25
	14	35.5	3.75	0.25

3. PEEM3 90 degree mirror column.

PEEM3 90 degree mirror column is used for aberration correction. It consists of field lens, mirror, electric-magnetic dodecapole, projector and CCD camera. PEEM3 electron mirror has four rotationally symmetric electrodes and the reflecting electrode is of circle shape with radius 5.6mm. The inner electrode is put at ground voltage, while the potentials of other electrodes give three free knobs to determine the focal length, the chromatic aberration and the spherical aberrations of the mirror.

Due to the compact design of the magnetic beam separator, it is difficult to put a beam monitor within it. A projector lens and CCD detector are located behind the mirror, which is used as a diagnostic PEEM. This PEEM has similar resolution to our present PEEM2 system. It allows to independently test and optimize the first sector of the beam separator and to independently optimize the incoming and outgoing beam at the mirror. In the diagnostic mode, the mirror acts as an unipotential lens and the electron beam passes through a central hole with a diameter of 500 micron at the reflecting electrode.

The layout of 90 degree mirror column is shown in fig.5. It consists of a five electrode lens, aperture, mirror lens, projector lens, CCD camera. Taking the exit plane of the magnetic separator as a reference plane, the outer surface of the first electrode of the field lens is located at 6mm, the back focal plane aperture is 70.81mm, the last electrode of the mirror is at 247mm, the center of projector lens is at 314.75, and the image plane is at 426.74mm.

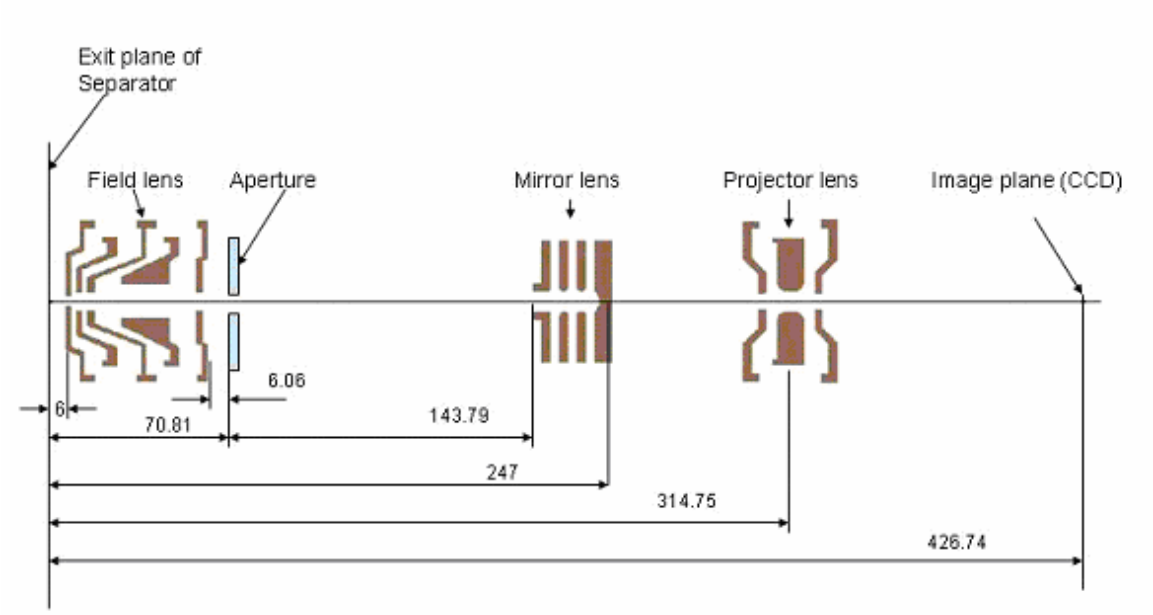


Fig.5 PEEM3 mirror column layout

The detail dimension of the lens and mirror are as following.

1). Five electrode lens:
Fig.6 gives the dimension and the coordinate convention of this field lens

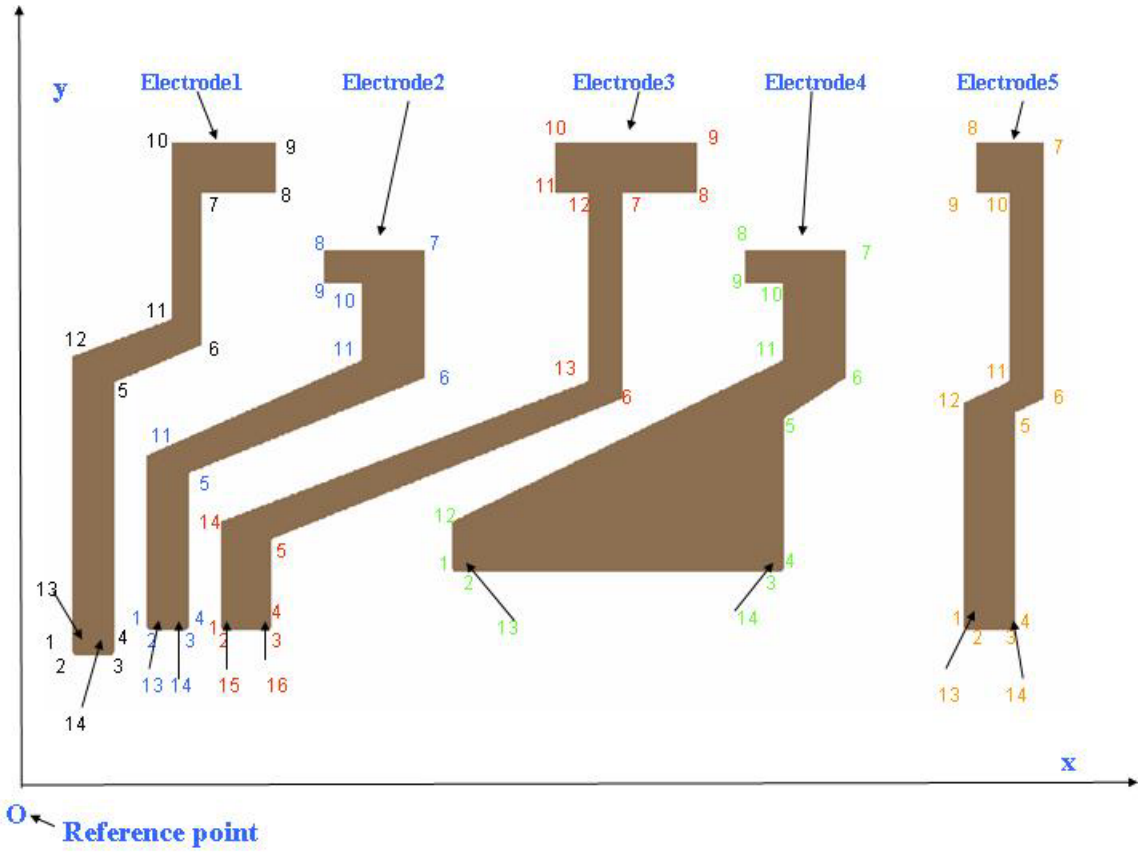


Fig.6 Convention for the five electrode lens coordinates. The number in the figure is the order of the coordinate. Different colors of the number corresponds to different electrodes. O is the reference point.

The coordinates of different electrodes for the field lens are as following:

	Order	x(mm)	y(mm)	Radius (mm)
Electrode 1	1	23.75	2.25	
	2	24	2	
	3	26	2	
	4	26.25	2.25	
	5	26.25	18.5	
	6	31.5	20.75	
	7	31.5	30	
	8	36	30	
	9	36	32.95	
	10	29.75	32.95	
	11	29.75	22.25	
	12	23.75	20	
	13	24	2.25	0.25
	14	26	2.25	0.25
Electrode 2	1	28.25	3.75	
	2	28.5	3.5	
	3	30.5	3.5	
	4	30.75	3.75	
	5	30.75	13	
	6	45	18.75	
	7	45	26.45	
	8	39	26.45	
	9	39	24.5	
	10	41.25	24.5	
	11	41.25	19.75	
	12	28.25	14	
	13	28.5	3.75	0.25
	14	30.5	3.75	0.25
Electrode 3	1	32.75	3.75	
	2	33	3.5	
	3	35.5	3.5	
	4	35.75	3.75	
	5	35.75	9	
	6	57	17.5	
	7	57	30	
	8	61.5	30	
	9	61.5	32.95	
	10	53	32.95	
	11	53	30	
	12	55	30	
	13	55	18.5	
	14	32.75	10	
	15	33	3.75	0.25
	16	35.5	3.75	0.25
Electrode 4	1	46.75	7.25	
	2	47	7	
	3	66.5	7	

	4	66.75	7.25	
	5	66.75	16.3	
	6	70.5	18.75	
	7	70.5	26.45	
	8	64.5	26.45	
	9	64.5	24.5	
	10	66.75	24.5	
	11	66.75	19.75	
	12	46.75	10	
	13	47	7.25	0.25
	14	66.5	7.25	0.25
Electrode 5	1	77.75	3.75	
	2	78	3.5	
	3	80.5	3.5	
	4	80.75	3.75	
	5	80.75	16.65	
	6	82.5	17.5	
	7	82.5	32.95	
	8	78.5	32.95	
	9	78.5	30	
	10	80.5	30	
	11	80.5	18.5	
	12	77.75	17.2	
	13	78	3.75	0.25
	14	80.5	3.75	0.25

2) Mirror
Fig.7 gives the dimension and the coordinate convention of the mirror

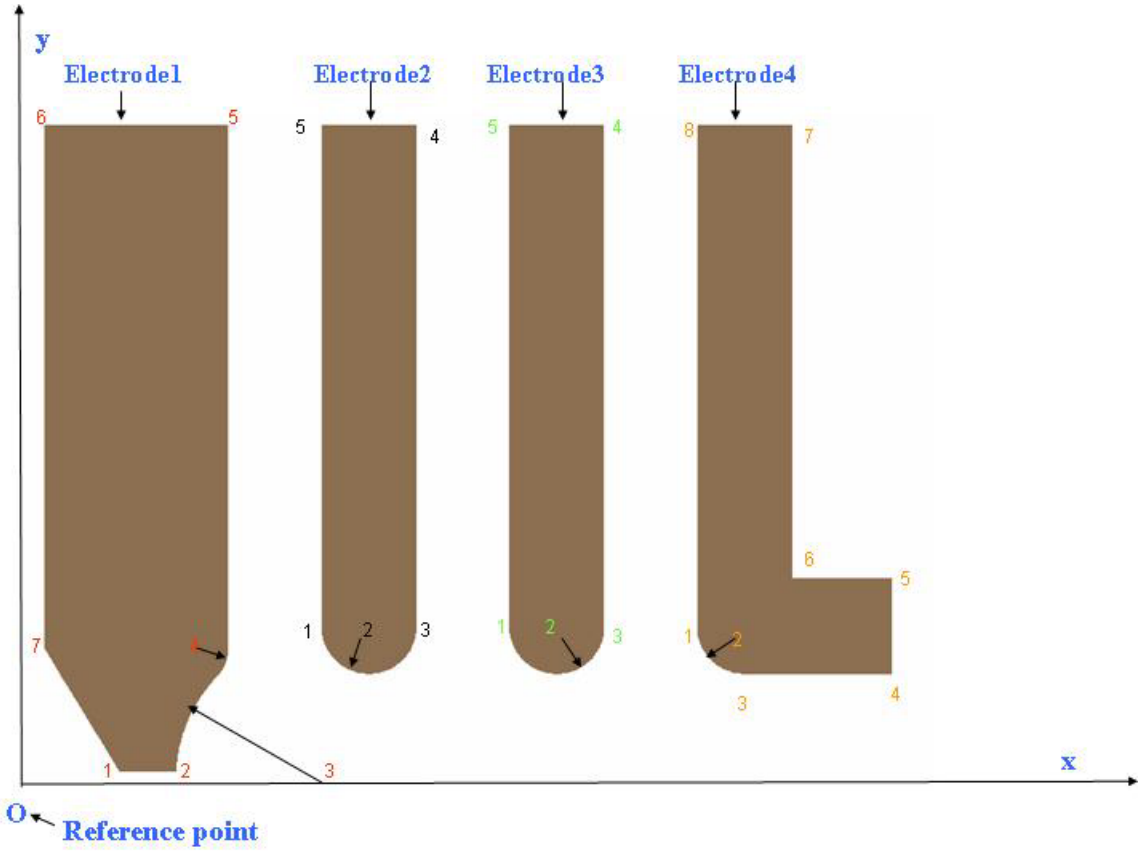


Fig.7 Convention for the mirror coordinates. The number in the figure is the order of the coordinate. Different color of the number corresponds to different electrodes. O is the reference point.

The coordinates of different electrodes for the mirror are as following;

	Order	x(mm)	y(mm)	Radius (mm)
Electrode 1	1	6	0.25	
	2	8.0056	0.25	
	3	13.6	0	5.6
	4	8.2	5.0596	1.8
	5	10	24.95	
	6	3	24.95	
	7	3	4.9	
Electrode 2	1	13.6	5.8	
	2	15.4	5.8	1.8
	3	17.2	5.8	
	4	17.2	24.95	
	5	13.6	24.95	
Electrode 3	1	20.8	5.8	
	2	22.6	5.8	1.8
	3	24.4	5.8	
	4	24.4	24.95	
	5	20.8	24.95	
Electrode 4	1	28	5.8	
	2	29.8	5.8	1.8
	3	29.8	4	
	4	35.4	4	
	5	35.4	7.6	
	6	31.6	7.6	
	7	31.6	24.95	
	8	28	24.95	

3) Projector lens

Fig.8 gives the dimension and the coordinate convention of the projector lens

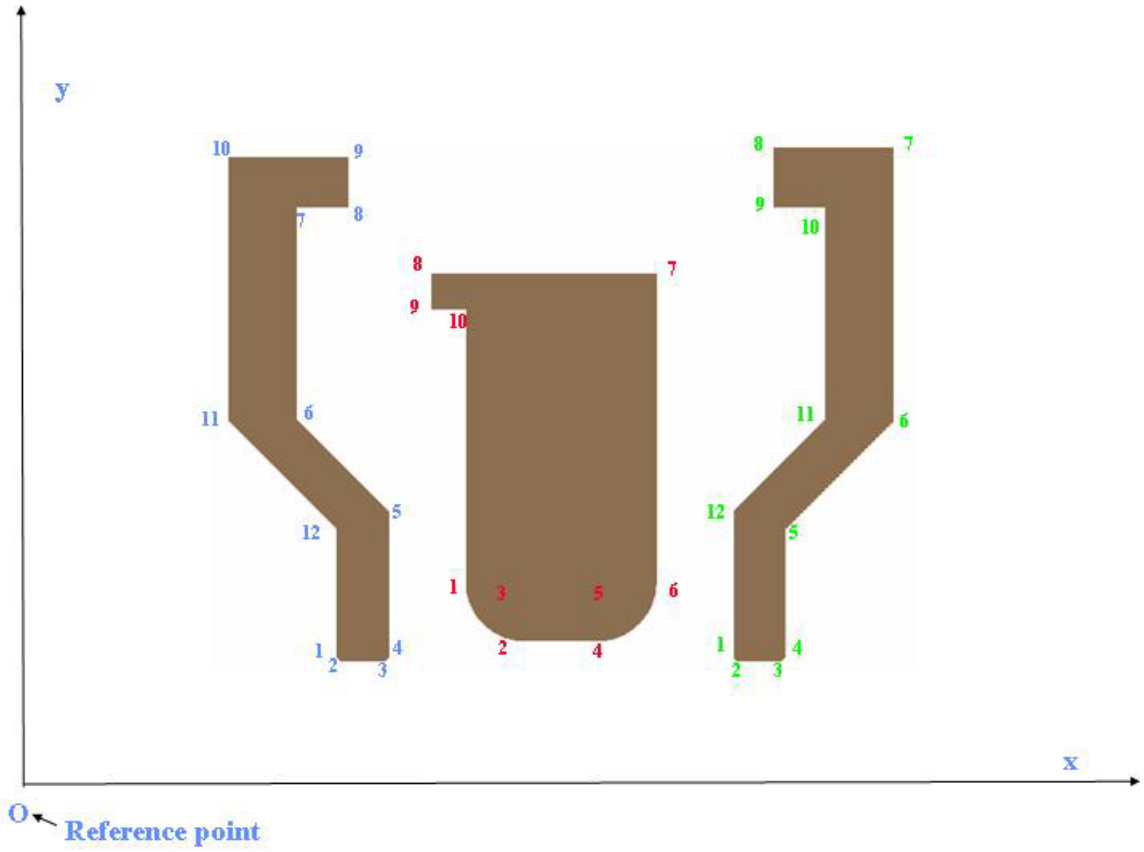


Fig.8 Convention of intermediate lens coordinates. The number in the figure is the order of the coordinate. Different colors of the number corresponds to different electrodes. O is the reference point.

The coordinates of different electrodes for the transfer lens are as following:

	Order	x(mm)	y(mm)	Radius (mm)
Electrode 1	1	21.4	3.45	
	2	21.65	3.2	
	3	24.15	3.2	
	4	24.4	3.45	
	5	24.4	12	
	6	19	17.4	
	7	19	30	
	8	22	30	
	9	22	32.9	
	10	15	32.9	
	11	15	17.4	
	12	21.4	11	
Electrode 2	1	29	7.9	
	2	32.5	4.4	
	3	32.5	7.9	3.5
	4	36.7	4.4	
	5	36.7	7.9	3.5
	6	40.2	7.9	
	7	40.2	26.05	
	8	27	26.05	
	9	27	24	
	10	29	24	
Electrode 3	1	44.8	3.45	
	2	45.05	3.2	
	3	47.55	3.2	
	4	47.8	3.45	
	5	47.8	11	
	6	54.2	17.4	
	7	54.2	33.5	
	8	47.2	33.5	
	9	47.2	30	
	10	50.2	30	
	11	50.2	17.4	
	12	44.8	12	

4. PEEM3 projector column

During the mechanical design of PEEM3, one issue raised is that the distance between the separator exit plan and transfer lens is too tight to put deflector and beam diagnostic paddle. Since this transfer lens is operated to have unit magnification and increasing the distance means lowering the voltage and increase the aberrations. Here I increase the distance to 90mm from 65mm and rearrange the layout of the projector column and give the new nominate voltage for these lenses shown in fig.9.

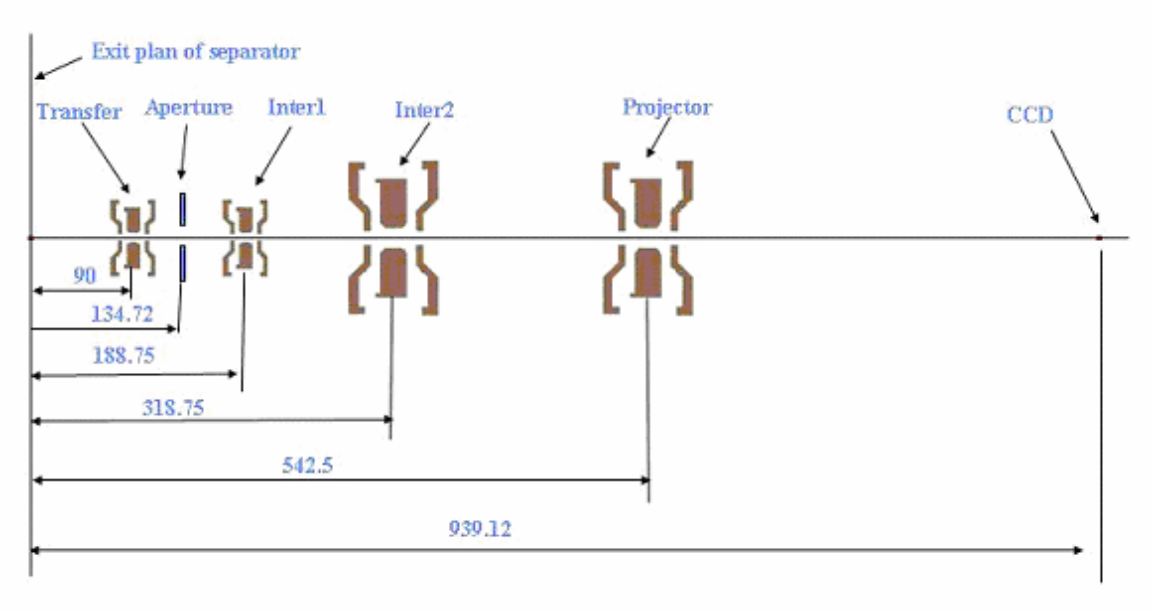


Fig.9 Projector column layout

Nominate voltage: Transfer lens: -11841.6v
Inter1 lens: 18440v
Inter2 lens: 19540v
Projector lens: 19371v

Aperture size in diameter: 10μm, 20μm, 50μm, 1000μm

The detail of the dimension for transfer and intermediate lens 1 is shown in fig.10

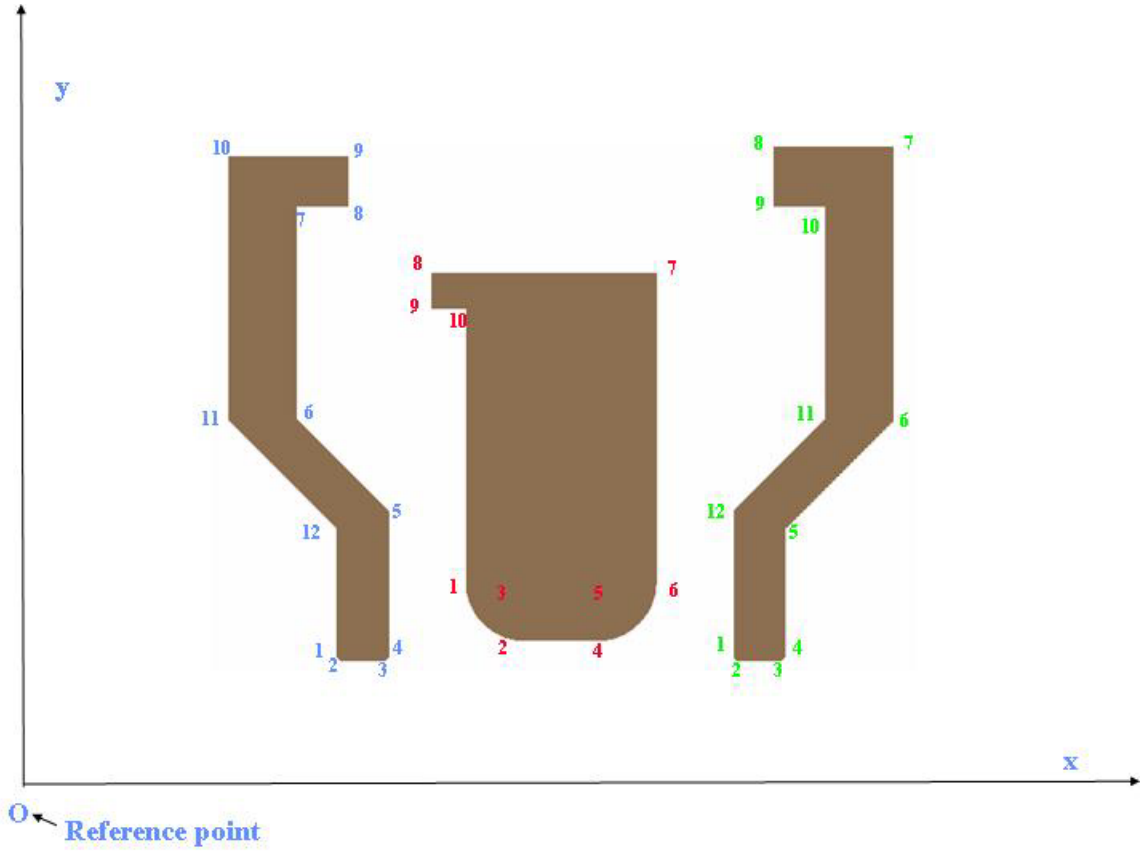


Fig.10 Convention of intermediate lens coordinates. The number in the figure is the order of the coordinate. Different color of the number corresponds to name different electrodes. O is the reference point.

The coordinates of different electrodes for transfer lens are as following:

	Order	x(mm)	y(mm)	Radius (mm)
Electrode 1	1	21.4	3.45	
	2	21.65	3.2	
	3	24.15	3.2	
	4	24.4	3.45	
	5	24.4	12	
	6	19	17.4	
	7	19	30	
	8	22	30	
	9	22	32.9	
	10	15	32.9	
	11	15	17.4	
	12	21.4	11	
Electrode 2	1	29	7.9	
	2	32.5	4.4	
	3	32.5	7.9	3.5
	4	36.7	4.4	
	5	36.7	7.9	3.5
	6	40.2	7.9	
	7	40.2	26.05	
	8	27	26.05	
	9	27	24	
	10	29	24	
Electrode 3	1	44.8	3.45	
	2	45.05	3.2	
	3	47.55	3.2	
	4	47.8	3.45	
	5	47.8	11	
	6	54.2	17.4	
	7	54.2	33.5	
	8	47.2	33.5	
	9	47.2	30	
	10	50.2	30	
	11	50.2	17.4	
	12	44.8	12	

For inter2 and projector lens , they are just double size of transfer lens

5. Tolerance

Mechanical alignment tolerance

Table Mechanic alignment tolerance			
Element	ΔZ(mm)	ΔY(mm)	Δθ(mrad)
Objective	1.0	0.1	15
FL1	1.0	0.2	30
Mirror	1.0	0.2	15
FL2	1.0	0.2	30

ΔZ: longitudinal direction
ΔY: transversal direction
Δθ: tilt

6. PEEM3 resolution

In our model to determine the resolution of PEEM3, the secondary electron distribution is used. We create a statistical ensemble of electrons with initial energy and angle spread and track the electron beam distribution weighted with the probability anywhere in the system. The resolution is defined as 68% in intensity of the point spread function. The effect of diffraction is calculated for each energy electron and summed up incoherently to yield a diffraction Airy pattern. The comparison of resolution versus transmission for PEEM2 and PEEM3 is shown in fig.11. Operating at 20kV and 2mm working distance, the point resolution for more than 90% transmission reaches 50nm with the mirror corrector, a significant reduction from that of 440nm without correction. The best resolution can be achieved is 5nm at 2% transmission, as opposed to 20nm at 1% transmission of PEEM2. The PEEM3 system should give a throughput around 50 x that of PEEM2 at 50 nm resolution, and should get to less than 10nm resolution in routine operation.

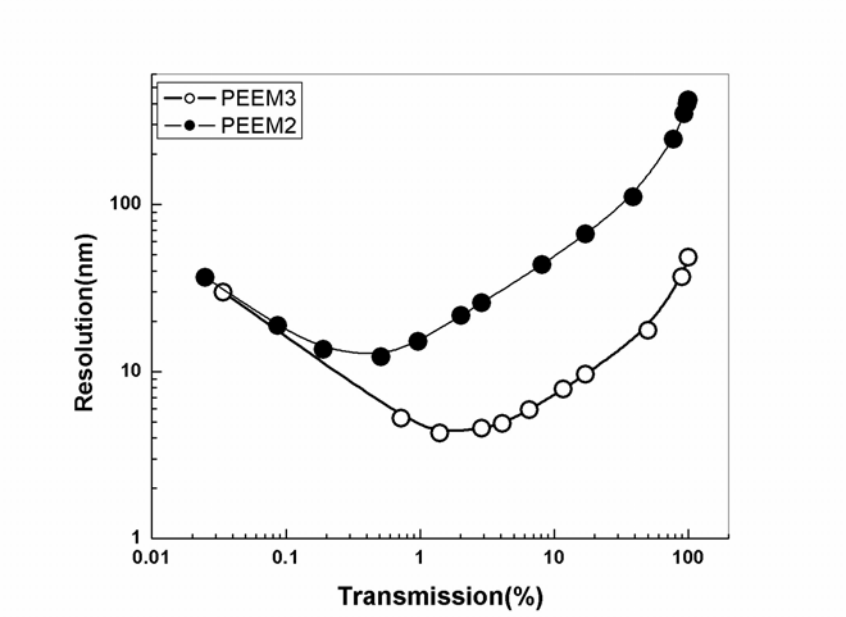


Figure 11. Comparison of resolution versus transmission of PEEM2 and PEEM3.